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TRUST End-of-Year Report

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CONTENTS

The objective of the Delivery Environments (DE) Testbeds to Reduce Uncertainties in Simulations and Tests (TRUST) work package is to quantify and help increase confidence in specific areas of computational and experimental capabilities that are applicable to current and future delivery environments. More complete quantification of confidence in experimental and computational capabilities and the sufficient increase of confidence in those capabilities is critical to improving weapons engineering design, qualification, and assessment efforts that are critical to the current and future stockpile. Staff development will include cross-discipline training to provide engineers with experience in both numerical simulations and experimental methods. This work will use and provide feedback on analysis tools and experimental results databases for efficient and responsive engineering which are currently under development: engineering common model framework (ECMF), engineering quantification of margins and uncertainties (EQMU), and the test information management system (TIMS).

TRUST includes four testbeds and their associated engineering analysis baseline models (EABMs):

1. contact thermal conductivity (CTC)
2. nonlinear dynamics (ND)
3. sensors in environments for accelerometers (SEA)
4. sensors in environments for fiber optic displacement gages (SEFOD)

CHAPTER

ONE

INTRODUCTION

The Delivery Environments (DE) program work package Testbeds to Reduce Uncertainties in Simulations and Tests (TRUST) is designed to quantify and reduce the uncertainty associated with experimental testing and numerical simulation of large engineering assemblies to support the efficient and responsive development of future systems [1, 2, 3, 4]. Because engineering assemblies contain a large number of uncertainty sources, well-characterized testbeds must be designed to isolate individual uncertainty sources. Once quantified, uncertainty sources can be compared to direct research and development funding towards the largest sources driving behavior of interest. Quantified uncertainty may also be propagated through engineering simulations to determine quantitative confidence in simulation predictions and for comparison against uncertainty in the experimental measurements.

TRUST efforts in FY20 explored the possibilities for responsive collaborations between engineering analysis and experimental design and test groups. TRUST designed and began testing three testbeds as collaborations between the Advanced Engineering and Analysis (W-13) group with numerical modeling expertise and four groups with design and experimental engineering expertise [4].

1. Contact Thermal Conductance (CTC): Materials Science in Radiation and Dynamics Extremes (MST-8) [5, 6]
2. Nonlinear Dynamics (ND) in material behavior: Mechanical and Thermal Engineering (E-1) [7, 8]
3. Sensors in Environments Accelerometers (SEA) measurement uncertainty: Weapons Product Definition (W-11) and Test Engineering (E-14) [9, 10]

In FY20, the testbeds were exercised in unique sub-sets of the relevant engineering environments as appropriate to the uncertainty source. The CTC testbed isolates quasi-static thermal contact conductance in thermal environments and as a function of material combinations, material properties, surface roughness, and interface contact pressure. The ND testbed isolates material property nonlinearities in vibration environments and the SE testbed isloates uncertainty in accelerometer measurements in vibration environments as a function of vibration frequency.

CHAPTER

TWO

TESTBEDS

The TRUST efforts in FY21 expanded and refined previous work and added a fourth testbed collaboration.

1. Contact Thermal Conductance (CTC): Materials Science in Radiation and Dynamics Extremes (MST-8) [11, 12]
2. Nonlinear Dynamics (ND) in material behavior: Mechanical and Thermal Engineering (E-1) and National Security Education Center (NSEC) [13, 14]
3. Sensors in Environments Accelerometers (SEA) measurement uncertainty: Test Engineering (E-14) [15, 16]
4. Sensors in Environment Fiber Optic Displacement (SEFOD) measurement uncertainty: Test Engineering (E-14) and Weapons Product Definition (W-11) [17, 18]

Together, these testbeds established quantified uncertainty for experimental measurements (CTC, ND, SEA), propagated uncertainty through simulations (CTC, ND), and compared experimental results with simulation predictions (CTC, ND). Two testbeds used experimental uncertainty quantification (UQ) to drive testbed and experimental procedure design changes with quantified improvements in experimental certainty (ND, SEA). Finally, two testbeds were designed for uncertainty quantification of fiber optic displacement sensors, which will be used in continuing work beginning in FY22 (FOD). The three continuation projects continued developing and improving the version control and documentation for Engineering Analsyis Baseline Models (EABMs), including web-hosted HTML TRUST documentation [19]. The EABM solutions developed in TRUST have proved to be sufficiently mature for adoption by other simulation and analysis projects throughout W-13 [20].

The CTC testbed used an expanded test matrix with repeat tests and increased confidence in the measured test parameters [12]. This collaboration was one of the first projects to complete a full release of experimental data in the Test Information Management System (TIMS). The experimental analysis includes UQ of the expanded test matrix and uncertainty propagation through the associated EABM [11]. This project was one of the earliest adopters of the Engineering Quantification of Margins and Uncertainties (EQMU) Python package and provided valuable feedback to the package developers about usability and feature requirements [21].

The ND testbed experiments, experimental analysis, and simulations identified minor design modifications that improved the repeatability and reduced uncertainty in the linear configuration of the testbed using wave springs as a compliant material [14]. Throughout the experimental trouble-shooting and experimental UQ analysis process, this project continuosly uploaded experimental data to TIMS for communication to the simulation analyst for comparison. After the design modifications, the experimental UQ analysis and simulation predictions show improved agreement in preparation for nonlinear compliant material configurations planned as continuing work [13].

The SEA testbed experimental analysis identified large uncertainty associated with the small scale shaker [16]. The identification of large uncertainty was possible due to the rigid body nature of the original testbed design; however, the issues with the small scale shaker will require a new approach for UQ associated directly with accelerometers. A testbed and experiment re-design using hammer modal testing demonstrated reduced uncertainty with an improved UQ analysis [15]. These results are included in the FY22 planning for improved UQ experimental analysis. In addition to the novel UQ analysis, this project and the cross-discipline training program were used to on-board a new W-13 engineer. The testbed documentation and cross-discipline training for computational engineering have proved promising to reduce the on-boarding and training process within W-13.

The Sensors in Environments Fiber Optic Displacement (FOD) testbed was added in FY21 as an additional collaboration with E-14, with design and drawing package support from W-11. Prior to testbed design, a review of fiber optic displacement gage historic use at Los Alamos National Laboratory for engineering assembly experiments was performed [17]. Examples of past fibers were obtained and their cold-temperature performance compared against a new fiber design. These comparisons confirmed past cold temperature drop out behavior in some past fiber designs and demonstrated better behavior without dropouts for the newly designed and purchased fibers. Finally, two testbeds were designed to aid in quantifying uncertainty in fiber performance in a range of temperature environments for both constant and well-characterized displacement [18].

CHAPTER

THREE

CAPABILITY DEVELOPMENT

TRUST depends on several concurrent research and development (R&D) efforts for new and extended engineering tools:

1. Engineering common model framework (ECMF) [22]
2. Test information management system (TIMS) [23]
3. Engineering verification and validation tools (EV&V)
    1. Prophet [24]
    2. Engineering Quantification of Margins and Uncertainty (EQMU) [21]
4. Compressible, Hyperelastic, Isotropic, Porosity-based Foam model (CHIPFoam) [25, 26]

Throughout FY21, the TRUST project continued to test these engineering tools as early adopters. TRUST engineers provided valuable usability and feature requirement feedback, and in some case, participated in direct tool development and documentation.

The ECMF is a simulation data management tool designed to reduce the overhead associated with simulation management of large parametric studies, UQ propagation, and Bayesian calibration [27, 28]. This engineering tool is required as a build system for engineering simulation and analysis workflows to simplify the process of building simulations of large engineering assemblies and parametric studies. The ECMF is extended by the EQMU project, which provides ECMF workflow classes for performing engineering quantification of margins and uncertainties (EQMU). These two software projects provide the analysis framework that can achieve the primary goal of TRUST to provide greater confidence in experimental and computational capabilities. An automated, common modeling framework is also required for responsive and efficient computational modeling of engineering assemblies and collaborative development between analysts working on multiple projects.

TRUST contributed to ECMF development as early adopters in identifying bugs, submitting feature requests, defining user requirements, and in occasional direct development support. The TRUST simulation and analysis reports contain feedback on the interactions with the ECMF development team and the utility of the ECMF as a simulation build system [11, 13, 15]. TRUST also played a large role in establishing a new computational modeling ecosystem that started with ECMF development [29]. The largest contribution from the TRUST analysis team is a documented approach to building complete model suite documentation and reports in a version controlled EABM repository. In FY21, these efforts matured sufficiently to prompt adoption by simulation and modeling projects throughout W-13.

TIMS is a database designed specifically for storing and documenting test specific data generated from tests of engineering assemblies [23, 30]. Engineering assembly experiments generate data in more varied formats and types than materials and mechanical property testing. There is a need for a centralized database storing engineering assembly, qualification, and validation experimental data from the many distinct groups that generate this kind of data. Any such database requires a standard format, standard interfaces, and well defined guidelines and documentation for creating a complete description of the experiment and the data generated. TRUST shares all of these requirements for storing and organizing the experimental data generated from its testbeds.

TRUST contributed to the TIMS development as early adopters and in direct workflow and documentation development. The TRUST experimental and analysis reports contain an evaluation of the TIMS workflow and required development efforts to release TIMS as a production ready database [11, 12, 13, 14, 16].

There are several projects related to EV&V efforts in computational engineering. The projects directly relevant to TRUST are tied to computational engineering: the ECMF Python package [22], the EQMU Python package [21], and the Prophet Python Package [24]. These packages are used for

1. Sensitivity and parametric studies
2. Uncertainty quantification (UQ)
3. UQ propagation through simulation
4. Reduced order models (ROM)
5. Bayesian calibration

UQ of both experimental measurements and numerical simulation quantities of interest (QoI) is important to establishing quantitative confidence in engineering analysis. Propagating uncertainty through experimental data analysis and numerical simulation predictions can provide quantitative evaluations of engineering predictions. Adding capability for discrete statistical distributions and reduced order modeling techniques opens up the opportunity to perform Bayesian calibration on engineering simulations. Each of these EV&V tools are required for quantitative evaluation of confidence in engineering QoI and on the relative importance of continuing and future R&D efforts to engineering confidence in priority QoI. In FY21, TRUST began using the EV&V EQMU package for UQ propagation as an extension of the ECMF. As the UQ propagation and related EV&V tools mature, TRUST will begin exercising the EQMU ROM and Bayesian calibration tools in future FYs.

Material and interface models are significant sources of uncertainty in computational engineering. Many engineering applications require advanced R&D models for specific applications where the physics of the physical phenomena are not adequately captured by traditional engineering models. The TRUST nonlinear dynamics from materials in dynamic environments testbed exercises foam materials in an environment that requires an advanced R&D engineering material model. The CHIPFoam constitutive material model addresses many features of foam behavior and is under development to improve the range of behaviors and environments that it is capable of describing [25, 26]. The material nonlinear dynamics testbed continues to exercise foam materials in dynamic environments that push the boundary of foam material calibration data and will likely require the most advanced engineering scale material model available. TRUST testbeds, such as the material nonlinear dynamics testbed, are an excellent opportunity to evaluate confidence in advanced material models. As testbeds mature, TRUST will exercise CHIPFoam in more environments and add new material models to current and future testbeds.

TRUST added a staff development effort in FY21 targeting cross-discipline training. The pilot program introduced TRUST engineers to both the experimental and computational tools required by TRUST projects. E-14 engineers developed a hands on experimental modal testing curriculum attended by W-13 engineers [16]. W-13 engineers developed a computational engineering tools training attended by the entire TRUST team, experimentalists and computational analysts alike. The pilot project was successful in building a stronger understanding of the workflows and tools used by experimentalists and computational engineers across three divisions and four groups (E-1, E-14, NSEC, and W-13) and proved to be instrumental in on-boarding new W-13 staff to the TRUST project. The computational training was opened to all W-13 staff members after the TRUST pilot project and feedback from staff recommended extending the curriculum to additional topics in future FYs [31].

CHAPTER

FOUR

SUMMARY

The Delivery Environments (DE) program work package Testbeds to Reduce Uncertainties in Simulations and Tests (TRUST) is designed to quantify and reduce the uncertainty associated with experimental testing and numerical simulation of large engineering assemblies to support the efficient and responsive development of future systems. Because engineering assemblies contain a large number of uncertainty sources, well-characterized testbeds must be designed to isolate individual uncertainty sources. In FY20, three single feature testbeds were fabricated, characterized, and exercised: contact thermal conductance (CTC), nonlinear dynamics (ND) through material behavior, and experimental instrumentation or sennsors in engineering environments (SEA). Three EABMs were designed to provide matching simulation predictions and uncertainty propagation.

In FY21, these three testbeds were exercised to provide experimental data for uncertainty quantification analysis and comparison against simulations. All three testbeds provided experimental data UQ analysis, and two testbeds provided comparisons between experimental data and simulation predications with UQ propagation or sensitivity studies (CTC and ND). The experimental UQ analysis provided quantitative evidence to drive testbed and experimental design changes for the ND and SEA testbeds. After the re-designs, the UQ analysis demonstrated quantitative improvements in experiment repeatability and analysis results. All three testbeds uploaded data to the test information management system (TIMS) database and the SEA testbed provided TIMS comparisons to the Weapons Engineering Test Data Library (WETDL).

A fourth testbed was added to study fiber optic displacement gages (SEFOD), first with a research study and experimental confirmation of the cold temperature behavior of historic fiber builds. New fiber builds were designed as a result of this study, with experimental evidence of improved cold temperature behavior. Two SEFOD testbeds were designed and fabricated to perform UQ analysis of constant and well-characterized displacement in temperature environments.

TRUST continued contributing to concurrent capability development projects as early adopter testing, user requirements, feature requirements, and in some cases, direct development and documentation efforts. These projects included the Engineering Common Model Framework (ECMF), Engineering Quantification of Margins and Uncertainties (EQMU), Prophet, TIMS, and Engineering Analysis Baseline Model eco-system for version control and documentation. In collaboration with these projects, TRUST developed a novel cross-discipline training program to provide hands on experimental and computational workflow and tools training for experimental and computational engineer across four groups: E-1, E-14, NSEC, and W-13. The computational half of this training was opened to all W-13 staff and concluded with requests to extend the program to include additional topics.

Continuing work will exercise all four testbeds in expanded test matrices and for validation experiments. A new sensors in environment testbed will explore uncertainty quantification for thermo-couples and on-board two new staff members, one in E-14 and one in W-13. The cross-discipline training will be continued for staff development of the TRUST team, and the computational engineering training will be expanded for W-13 and collaborative groups. As in FY21, TRUST engineers will continue to contribute to related projects as necessary for the TRUST objective of improving confidence in experimental and computational engineering.

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